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REPORT NO. ~~648/4~~ 642.7/4

BUTT WELDS

ALUMINUM ALLOY 17 ST

ELECTRIC ARC AND OXY-ACETYLENE METHODS

1/8" AND 1/4" ROLLED SHEET

5% SILICON ALUMINUM FILLER

BY

W. L. WARNER

1933

REPORT NO. ~~648/4~~ 642.7/4 FEBRUARY 1, 1933

WATERTOWN ARSENAL

BUTT WELDS

ALUMINUM ALLOY 17 ST

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A. OBJECT

THIS INVESTIGATION WAS STARTED TO DETERMINE:

(1) THE STRENGTH OF JOINT OBTAINABLE WITH EITHER THE ARC OR GAS WELDING PROCESSES ON ROLLED DURALUMINUM SHEET SUCH AS IS USED FOR VARIOUS PARTS OF THE 3" A.A. GUN MOUNT.

(2) THE EFFECT OF CORROSION, HEAT TREATMENT, HEAT TREATMENT AND CORROSION, AND AGING ON-

(A) THE STRENGTH OF THE JOINT.

(B) THE HARDNESS OF THE WELD AND THE HEAT AFFECTED ZONES ADJACENT TO THE WELD.

(3) THE CORRECT WELD PROCEDURE TO OBTAIN THE BEST WELD STRENGTH.

B. CONCLUSIONS

1. THE AVERAGE EFFICIENCY OF THE WELDED JOINT "AS WELDED" IS 55-60% WITH EITHER THE GAS OR ARC METHODS.

2. THE CORROSION TREATMENT, AS USED IN THIS STUDY, IMPROVES THE STRENGTH SLIGHTLY.

3. HEAT TREATMENT ALONE OR WITH THE ADDITION OF THE CORROSION TREATMENT INCREASES THE JOINT EFFICIENCY TO ABOUT 75% FOR THE ARC WELD BUT DOES NOT AFFECT THE GAS WELD APPRECIABLY.

4. AN AGING OF SIX MONTHS DOES NOT AFFECT THE STRENGTH OF THE JOINT BUT DECREASES THE DUCTILITY SOMEWHAT.

5. THE SOFTENING EFFECT OF THE WELDING HEAT ON THE PARENT METAL IS NOT CHANGED BY SIX MONTHS AGING.

6. ON 1/8" SHEET MAXIMUM STRENGTH IS OBTAINED WITH THE ARC AT A CURRENT OF ABOUT 75 AMPERES. NO PHYSICAL TESTS WERE MADE ON 1/4" SHEET WELDED WITH THE ARC.

7. ON BOTH THE 1/8" AND 1/4" SHEET WELDED WITH THE GAS FLAME A BACKING OF GRAPHITE GAVE BEST RESULTS AS TO SMOOTHNESS OF WELD AND EASE OF MANIPULATION.

8. WHEN MAKING A GAS BUTT WELD THE PLATE EDGES MUST BE SLIGHTLY PREHEATED TO PREVENT CRACKING OF THE PLATE ALONGSIDE THE WELD ON COOLING.

C. SCOPE OF THE TESTS

(1) ARC WELD

EXPERIMENTS WITH THE ARC WERE CONFINED MOSTLY TO 1/8" SHEET USING THE ALCOA 1/8" COVERED 5% SILICON WELDING ELECTRODE. THE COATING ON THIS ELECTRODE WAS ALCOA #25 FLUX. AMPERAGES OF FROM 60 TO 90 REVERSED POLARITY WERE USED.

(2) Gas Weld

Experiments with the oxy-acetylene flame were made on both 1/8" and 1/4" sheet using a #6 and #9 tip, respectively, and a slightly carbonizing flame.

A bevel was not used for any of the tests. With the gas process a 5% silicon filler rod was used with Alcoa #22 aluminum welding flux.

(3) Tensile Test

The shape of the specimens was as shown in Fig. No. 2. All welds were tested by this test. For heat treatment and corrosion the specimens were first machined for tensile testing and then given the treatment as follows:

(a) Heat Treatment

Specimens heated to 950°F while immersed in soda nitrate and held at temperature for fifteen minutes after which they were given a water quench.

(b) Corrosion

The solution was normal salt (58.5 gm. NaCl in a liter of distilled water) to which was added 10% (by volume) of hydrogen peroxide (3% stock solution).

Each specimen was immersed for 1½ minutes and held out for 1½ minutes continuously for 48 hours. At the conclusion of this treatment the specimens were broken in the testing machine.

D. Welds Tested

(1) Arc

The welded plates were approximately of the dimensions shown by A in Fig. No. 1.

The general procedure was to weld either two or four of these plates under the same conditions.

Table I

(1/8" Dural)

Plate	Amp	Volts	Separation	Welded	Remarks
11A	60/65	20/22	1/32"	7/17/31	
16A	90/95	20/25	0"	7/22/31	Rods dried out in an electric furnace for approximately $1\frac{1}{2}$ hours at about 75° C.
B	"	"	"	"	
17A	75/80	20/25	0"	"	
B	"	"	"	"	
21A	75/80	20/25	0"	7/23/31	Rods dried out and used warm. Held approx. 1 hour at 75° C.
B	"	"	"	"	
C	"	"	"	"	
D	"	"	"	"	
22A	90	20/25	0"	7/24/31	Two coats of collodion on dry rod.
B	"	"	"	"	
C	"	"	"	"	
D	"	"	"	"	
23A	90	20/25	0"	7/24/31	Rods dried out no collodion
B	"	"	"	"	
C	"	"	"	"	
D	"	"	"	"	

In welding these plates they were clamped flat with a backing strip of copper in which was machined a groove 1/32" deep and 1/4" wide.

Plates C and D, 16B, and 17A were held for six months aging test. The remaining plates were cut up into test specimens as shown in A, Fig. No. 1, the specimens being machined as shown by Fig. No. 2. From plates 21B, 22B, and 23B no hardness specimens were machined so that specimens #3 and #4 of those plates correspond to specimens #4 and #5 of the others. With plates 21A and 23A the hardness specimens were machined from strip #5 so that they bear the numbers 51 and 52 instead of 31 and 32.

The test to which each of the specimens from the various plates was submitted was as follows:

#1 - Tensile as welded

#2 - Tensile as corroded

#4 - Tensile after heat treatment*

#5 - Tensile after heat treatment and corrosion*

#31- Hardness as welded*

#32- Hardness as heat treated*

*With the exceptions above noted.

TABLE II

STRENGTH OF UNWELDED PLATE (1/8" DURAL)

SPECIMEN	DIRECTION OF STRESS APPLICATION	TENS.STR. LBS/SQ.IN	ELONG.4" %
1-A	PREPENDICULAR TO	61,280	19.5
2-A	DIRECTION OF ROLLING	59,680	18.2
1-B	PARALLEL TO	61,760	20.2
2-B	DIRECTION OF ROLLING	60,800	19.0

TABLE III

STRENGTH OF WELD "AS WELDED" (1/8" DURAL)

PLATE	SPECIMEN	TENS. STR. LBS/SQ.IN	ELONGATION % 1"	4"
11A	1	32,160*	5.0	4.0
16A	1	34,720	4.0	1.2
17B	1	36,960	4.0	1.2
21A	1	37,440	3.0	1.0
B	1	30,880	3.0	1.0
22A	1	29,280	3.0	1.0
B	1	32,160	4.0	1.3
23A	1	35,040	3.0	1.0
B	1	28,800	2.0	0.8

*FAILED THROUGH WELD METAL. EXCEPT WHERE OTHERWISE NOTED ALL SPECIMEN FRACTURES OF ARC WELDS OCCURRED AT THE EDGE OF THE WELD.

Table IV

Strength of Weld "After Corrosion" (1/8" Dural)

Plate	Specimen	Tens. Str. lbs/sq. in.	Elongation % 1"	Elongation % 4"
11A	2	36,320	5.0	2.3
16A	2	34,720	5.0	2.0
17B	2	37,760	5.0	1.2
21A	2	37,280	5.0	1.5
B	2	33,600	3.0	1.0
22A	2	30,080	3.0	1.0
B	2	32,640	3.0	1.0
23A	2	24,960	3.0	1.0
B	2	32,320	3.0	1.0

Table V

Strength of Weld "After Heat Treatment" (1/8" Dural)

Plate	Specimen	Tens. Str. lbs/sq. in.	Elongation % 1"	Elongation % 4"
11A	4	29,760	4.0	1.8
16A	4	45,600	8.0	4.5
17B	4	47,840	8.0	5.5
21A	3	45,760	4.0	3.3
B	3	44,800	5.0	3.3
22A	4	37,760	5.0	1.5
B	3	34,240	3.0	0.8
23A	3	39,200	4.0	1.5
B	3	37,760	3.0	1.5

TABLE VI

STRENGTH OF WELD "AFTER HEAT TREATMENT & CORROSION"

(1/8" DURAL)

PLATE	SPECIMEN	TENS. STR. LBS/SQ.IN.	ELONGATION % 1"	4"
11A	5	36,800	4.0	1.2
16A	5	48,560	7.0	4.8
17B	5	49,120	7.0	5.5
21A	4	48,160	6.0	3.8
B	4	40,160	5.0	1.8
22A	5	36,160	3.0	1.0
B	4	44,640	6.0	2.5
23A	4	34,240	3.0	1.2
B	4	43,360	6.0	3.0

The results of the Rockwell hardness tests made on these welds are shown graphically in Fig. No. 3.

The results given in Tables III to VI inclusive are taken from Test Report No. 648/1, dated August 5, 1931.

TABLE VII

STRENGTH OF WELD "AFTER 6 MO. AGING" (1/8" DURAL)

PLATE	SPECIMEN	TENS. STR. LBS/SQ.IN.	ELONGATION % 2"	4"
16B	1	36,000	1.5	0.75
	2	38,400	2.0	1.0
17A	1	40,000	2.0	1.25
	2	41,600	2.0	1.25
21C	1	36,800	1.5	1.0
	2	43,200	2.0	1.5
D	1	32,000	1.0	0.75
	2	33,600	1.0	0.75
22C	1	32,000	0.5	0.5
	2	38,400	1.0	0.875
D	1	33,600	1.0	0.75
	2	35,200	1.0	1.0
23C	1	38,400	2.0	1.5
	2	35,200	1.5	1.0
D	1	28,800	1.0	0.75
	2	38,400	2.0	1.25

THE RESULTS GIVEN IN TABLE VII ARE TAKEN FROM TEST REPORT NO. 648/1-1, DATED MAY 10, 1932.

THE RESULTS OF THE ROCKWELL HARDNESS TESTS MADE ON THESE WELDS ARE SHOWN GRAPHICALLY IN FIG. NO. 4.

THERE WERE NO TESTS MADE OF WELDS WITH THE METAL ARC ON 1/4" DURALUMINUM SHEET.

OXY-ACETYLENE

THE WELDED PLATES WERE APPROXIMATELY OF THE DIMENSIONS SHOWN BY B OF FIG. NO. 1.

TABLE VIII (1/8" DURAL)

PLATE	TIP	BACKING	WELDED	REMARKS
41A	#6	FLAT GRAPHITE	7/31/31	NOT CLAMPED
B	"	NOT CLAMPED	"	#22 FLUX ON JOINT. WELD COOLED IN WATER TO REMOVE SLAG.
42A*	#6	"	7/31/31	SAME EXCEPT NOT COOLED IN WATER
43A	#6	CLAMPED ON	8/1/31	COOLED IN WATER
B	"	COPPER WITH GROOVE	"	NOT COOLED
		PLATE EDGES PREHEATED		
46A	#6	CLAMPED ON	8/1/31	NOT COOLED
B	"	GRAPHITE WITH GROOVE	"	IN WATER
		PLATE EDGES PREHEATED		

*NEUTRAL FLAME.

SEPARATION IN ALL CASES 1/16". FILLER 1/8" WITH #22 FLUX.

TABLE IX

STRENGTH OF WELD "AS WELDED" (1/8" DURAL)

PLATE	SPECIMEN	TENS. STR. LBS/SQ.IN.	ELONGATION % 1"	4"
41A	1	45,120*	4.0	6.8
	2	38,720	5.0	3.8
42A	1	39,680*	2.0	5.3
	2	39,040	6.0	4.8
43A	1	26,720	5.0	1.5
	2	30,400	5.0	1.8
46A	1	41,280*	8.0	4.3
	2	43,840*	10.0	5.0

*FRACTURE IN PLATE FROM 1/4" TO 1 1/2" FROM EDGE OF WELD. OTHERWISE FRACTURE THROUGH CENTER OF WELD. WELD FRACTURES OF GAS WELDS HAVE SAME APPEARANCE AS PLATE FRACTURES EXCEPT AS NOTED UNDER TABLE XIV.

TABLE X

STRENGTH OF WELD "AFTER 6 MO. AGING" (1/8" DURAL)

41B	1	43,200	3.5	4.25
	2	44,800*	2.5	6.0
43B	1	36,800	2.5	2.5
	2	35,200*	2.0	2.0
46B	1	33,600*	2.0	1.25
	2	40,000	3.5	3.0

*FRACTURE IN PLATE FROM 1/4" TO 1" FROM EDGE OF WELD.

The results of the Rockwell hardness tests on these welds after six months aging are shown in Fig. No.5.

The specimens of 1/4" duraluminum were similar to those of 1/8" sheet being machined as shown by Fig. No. 1. The tests made on the various specimens were as follows:

#1 & #5 - Tensile as welded.

#4 - Tensile as corroded.

#2 & #6 - Tensile as heat treated.

#3 - Tensile as heat treated and corroded.

Table XI

(1/4" Dural)

Plate	Tip	Backing	Welded	Remarks
61	#9	Graphite	10/9/31	1/4" filler with #22 flux and separation 3/16"
62	"	"	"	
63	"	"	"	
64	"	"	"	

Graphite backing had 3/16" wide groove approximately 1/16" deep.

Plates #63 and #64 were held for six months aging test.

TABLE XII

STRENGTH OF WELD "AS WELDED" (1/4" DURAL)

PLATE	SPECIMEN	TENS. STR. LBS/SQ.IN.	ELONGATION % 2"
61	1	24,800	2.0
	5	34,400	3.0
62	1	29,600	1.5
	5	33,600	3.0

ALL FRACTURES THROUGH WELD AND HAVE THE SAME APPEARANCE AS PLATE FRACTURES.

TABLE XIII

STRENGTH OF WELD "AS CORRODED" (1/4" DURAL)

PLATE	SPECIMEN	TENS. STR. LBS/SQ.IN	ELONGATION % 1"
61	4	32,000	4.0
62	4	34,400	4.0

STRENGTH OF WELD "AS HEAT TREATED"(1/4" DURAL)

			ELONGATION % 2"
61	2	33,600	5.0
	6	40,800	6.0
62	2	39,200	3.0
	6	43,200	4.0

STRENGTH OF WELD "AS HEAT TREATED & CORRODED"(1/4" DURAL)

61	3	34,400	4.0
62	3	33,600	5.0

Table XIV

Strength of Weld "After 6 mo. Aging" (1/4" Dural)

Plate	Specimen	Tens. Str. lbs/sq.in.	Elongation % 2"	Elongation % 4"
63	1	33,600	2.5	2.25
	2	33,600	2.0	2.5
64	1	40,000	3.0	3.75
	2	35,200	2.25	2.25

These specimens of 1/4" Dural sheet fractured through the weld metal exhibiting a metal structure somewhat coarser than that of the plate fracture.

The results of the Rockwell hardness test on these welds after six months aging are shown in Fig.No.5.

E. Summary

Table XV

Arc Weld 1/8" Plate

Treatment	Amp.	Tens. Str. Lbs/sq.in.	Elongation % 1"	Elongation % 4"
As welded	60	32,160	5.0	4.0
	75	35,090	3.3	1.1
	90	32,000	3.2	1.0
As corroded	60	36,320	5.0	2.3
	75	36,210	4.3	1.2
	90	30,940	3.4	1.2
As heat treated	60	29,760	4.0	1.8
	75	46,130	5.7	4.0
	90	38,910	4.6	2.0
As heat treated and corroded	60	36,800	4.0	1.2
	75	45,810	6.0	3.7
	90	41,390	5.0	2.5
			2"	4"
After 6 months aging	60	-	-	-
	75	37,870	1.6	1.1
	90	35,440	1.4	0.9

From these figures it may be seen that the welds made with 75 amperes show the greatest tensile

STRENGTH UNDER EACH OF THE ABOVE CONDITIONS OF TEST EXCEPT IN THE "AS CORRODED" CONDITION AND THIS DIFFERENCE IS SO SMALL AS TO BE PRACTICALLY NEGLIGIBLE. THIS EXCEPTION CANNOT BE ACCOUNTED FOR, HOWEVER.

THE FRACTURES WERE ALL ABOUT THE SAME, OCCURRING AT THE EDGE OF THE WELD, IN THE FUSION ZONE, AND IN ALL CASES SHOWED A LARGE AMOUNT OF FINE POROSITY. THE X-RAY FILMS SHOW THIS POROSITY TO BE GENERALLY DISTRIBUTED THROUGHOUT THE FUSION ZONE (TEST REPORT NO.648/1;8/5/31).

THE FRACTURES OF WELDS #22 AND #23 SHOWED CONSIDERABLE COARSE POROSITY IN THE FUSION ZONE AND THIS POROSITY IS SHOWN BY THE X-RAY FILMS TO BE GENERAL THROUGHOUT THE FUSION ZONE. THE PRESENCE OF THIS COARSE POROSITY SEEMS TO BE CHARACTERISTIC OF CURRENTS GREATER THAN 80 AMPERES ON THIS 1/8" DURALUMINUM SHEET WITH THE 1/8" ELECTRODE.

THE COLLODION USED TO COAT THE ELECTRODES IN THE CASE OF TEST #22 IS NOT BELIEVED TO BE THE PRIMARY CAUSE OF THE COARSE POROSITY NOTED SINCE COARSE POROSITY WAS ALSO NOTED IN TEST #23 IN WHICH NO COLLODION WAS USED. HOWEVER, IT MAY BE A CONTRIBUTING FACTOR AND YET THE USE OF COLLODION SEEMS TO OFFER SEVERAL ADVANTAGES.

THE ELECTRODES COATED WITH THE #25 FLUX ABSORB MOISTURE VERY READILY AND WHEN THIS HAPPENS THEY MUST BE DRIED OUT BEFORE THEY CAN BE USED SATISFACTORILY. WHEN DRY, A COATING OF COLLODION WILL PREVENT THE #25 FLUX from absorbing moisture and is very durable.

The collodion coated rod gives a smoother arc action even at somewhat higher current than when used without it and there is less spattering than in the latter case. Collodion was used at the suggestion of Dr. M. G. Yatsevitch of the Arsenal Laboratory.

From Table XV it will be noted that the 75 ampere welds show an efficiency in the "as welded" condition of about 58% which is increased to a maximum of about 77% in the "heat treated" condition. After six months aging the strength has increased only slightly, to about 63%.

The greatest trouble encountered with this method of welding was in making a smooth stop and start in changing electrodes. This operation could not consistently be accomplished as it requires constant practice and great skill on the part of the operator. There is practically no crater left when the arc is broken and due to the high heat conductivity of the plate the arc must be struck behind the crater and brought forward in order to obtain continuous weld penetration. If this is not done a small spot will be left at the forward edge of the crater where the weld has not penetrated completely through the joint.

This difficulty is not quite as troublesome on the 1/8" sheet as on thicker plate.

THE RESULTS OF THE HARDNESS TESTS SHOWN IN FIGS. NO. 3 AND 4 INDICATE NO APPRECIABLE SOFTENING OF THE PLATE BY THE WELDING HEAT AND AGING DOES NOT APPEAR TO CAUSE ANY CHANGE IN THIS CONDITION.

TABLE XVI

GAS WELD- 1/8" PLATE

TREATMENT	FLAME	BACKING	TENS.STR. LBS/SQ.IN.	ELONGATION % 1"	ELONGATION % 4"
AS WELDED	CARBON	GRAPHITE	41,920	4.5	5.3
	"	"	42,560*	9.0	4.6
	"	COPPER	28,560*	5.0	1.6
	NEUTRAL	GRAPHITE	39,360	4.0	5.0
AFTER 6 MO. AGING	CARBON	GRAPHITE	44,000	3.0	5.2
	"	"	36,800*	2.8	2.2
	"	COPPER	36,000	2.3	2.3

*PLATE EDGES PREHEATED.

FROM THESE FIGURES IT IS APPARENT THAT THE CARBURIZING FLAME WITH GRAPHITE BACKING GIVES GREATEST TENSILE STRENGTH. IN THE "AS WELDED" CONDITION THE COOLING OF THE WELD BY IMMERSION IN WATER AFTER WELDING SHOWS NO PRONOUNCED IMPROVEMENT BUT AFTER SIX MONTHS AGING THE WATER COOLED WELD SHOWS BEST AVERAGE STRENGTH.

PREHEATING OF THE PLATES BEFORE WELDING DOES NOT APPEAR FROM THESE TESTS TO IMPROVE THE STRENGTH EXCEPT IN THE "AS WELDED" CONDITION WITH THE GRAPHITE BACKING. HOWEVER, THE ADVANTAGE OF PREHEATING OF THE

PLATES APPEARS TO BE RATHER THAT OF PREVENTING CRACKING ALONGSIDE THE WELD ON COOLING, A CHARACTERISTIC WHICH IS NOT APPARENT FROM THE RESULTS OF PHYSICAL TESTS. THE ADVANTAGES OF PREHEATING SEEM TO BE MORE PRONOUNCED ON THE THICKER SHEET.

TABLE XVII

GAS WELD- 1/4" PLATE

CARBURIZING FLAME - GRAPHITE BACKING

TREATMENT	TENS.STR. LBS/SQ.IN	ELONGATION 1"	2"	4"
AS WELDED	30,600	-	2.4	-
AS CORRODED	33,200	4.0	-	-
HEAT TREATED	39,200	-	4.5	-
HEAT TREATED AND CORRODED	34,000	-	4.5	-
AFTER 6 MONTHS AGING	35,600	-	2.4	2.7

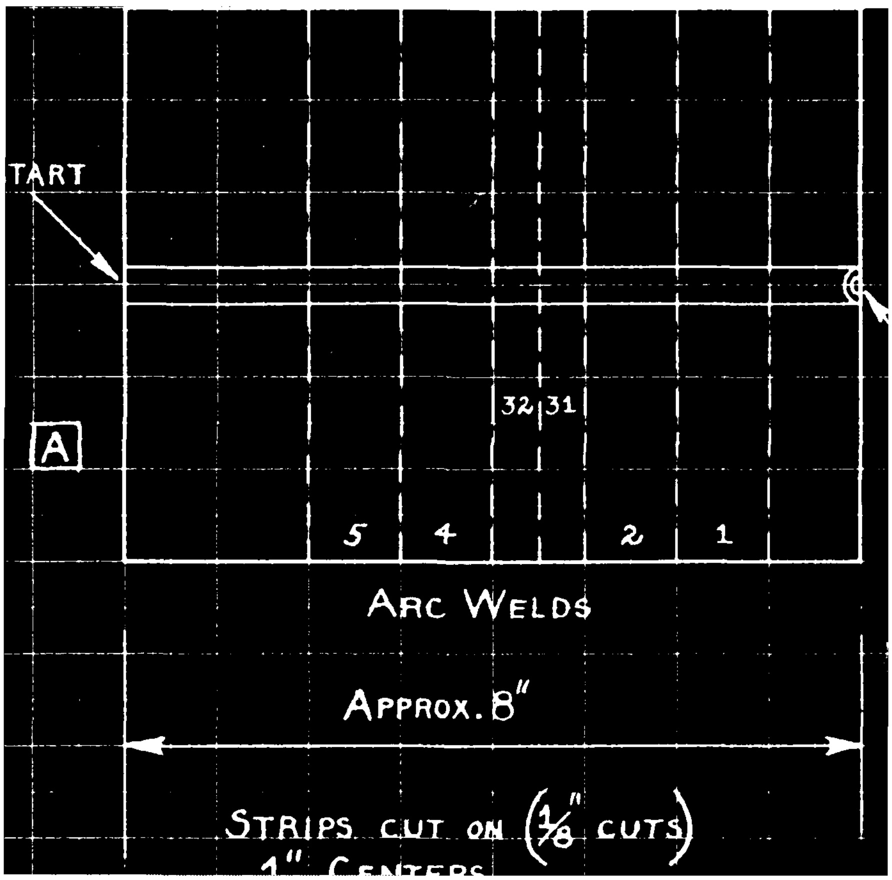
FROM THESE TEST RESULTS AND THOSE GIVEN IN TABLE XVI IT DOES NOT APPEAR THAT THE GAS WELDING METHOD GIVES AS HIGH STRENGTH OF WELDED JOINT AS THE ARC WELDING METHOD EXCEPT POSSIBLY THAT THE GAS WELDS HOLD UP BETTER THAN THE ARC WELDS ON AGING AND SHOW SLIGHTLY BETTER DUCTILITY.

THE COMPARATIVE SOFTENING EFFECTS ON THE PLATE OF THE TWO METHODS AFTER SIX MONTHS AGING ARE SHOWN BY THE CHARTS ATTACHED FIGS. #4 AND 5.

THE GREATEST DIFFERENCE BETWEEN THE TWO PROCESSES SEEMS TO BE THAT THE GAS PROCESS MAKES A SMOOTHER WELD AND ONE WHICH IS PRACTICALLY FREE FROM POROSITY.

RESPECTFULLY SUBMITTED

W. L. WARNER.



TART
A
32
31
5
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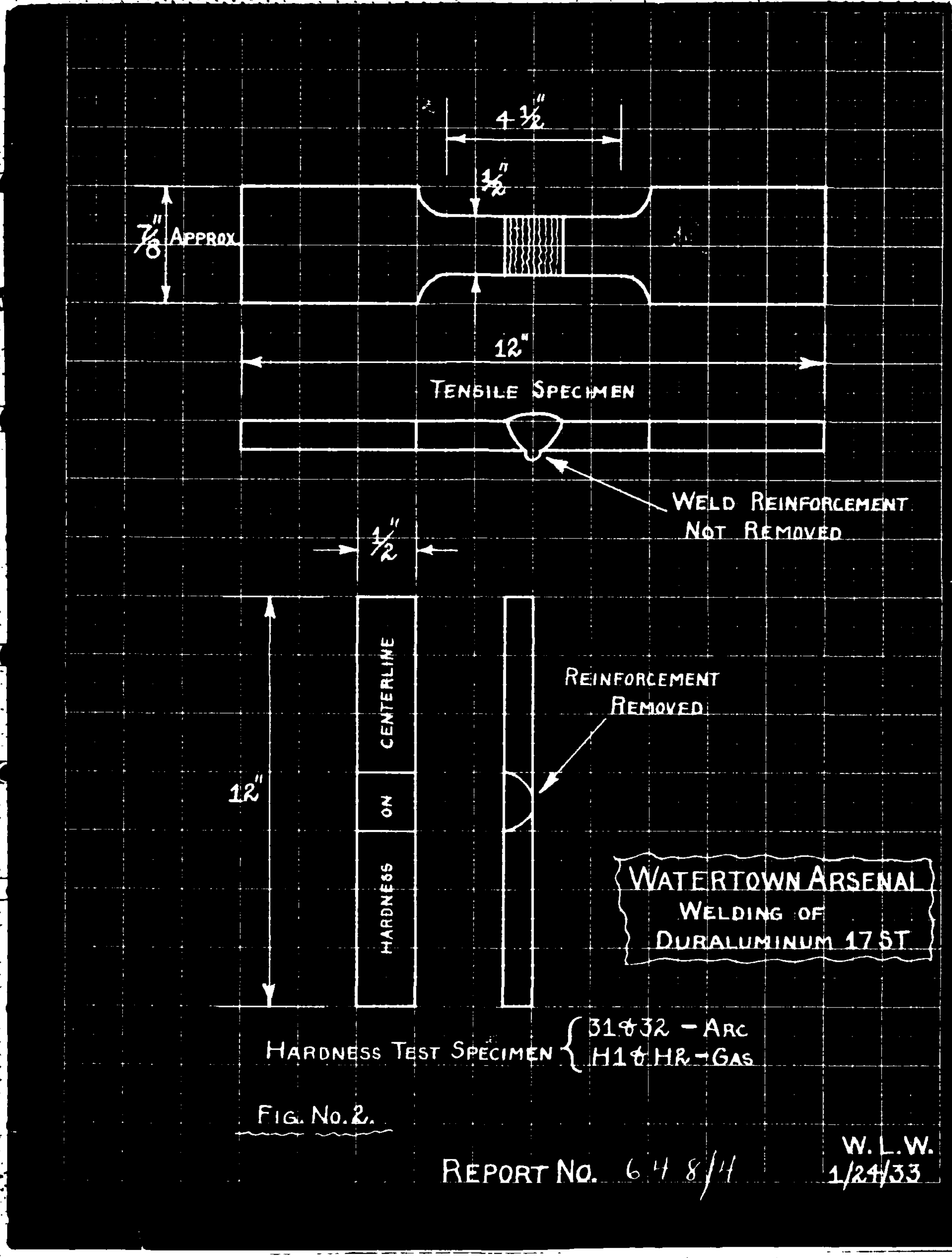
2
1
ARC WELDS
APPROX. 8"
STRIPS CUT ON 1" CENTERS
(1/8" CUTS)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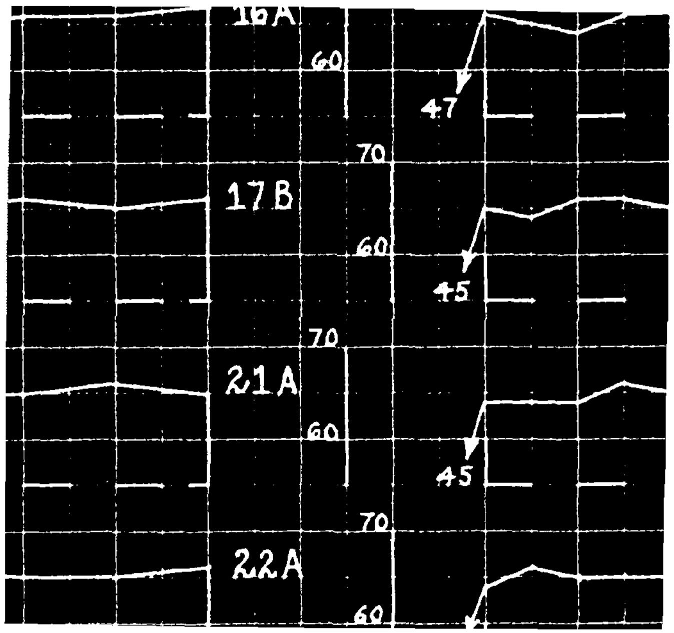
1/2"
7/8" Approx.
12"
Tensile Specimen
Weld Reinforcement Not Removed
1/2"
12"
Hardness on Centerline
Reinforcement Removed
Watertown Arsenal
Welding of Duraluminum 17 ST
Hardness Test Specimen
31 & 32 - Arc
H1 & H2 - Gas
Report No. 648/4
W. L. W.
1/24/33

Fig. No. 2.



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17B
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21A
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22A
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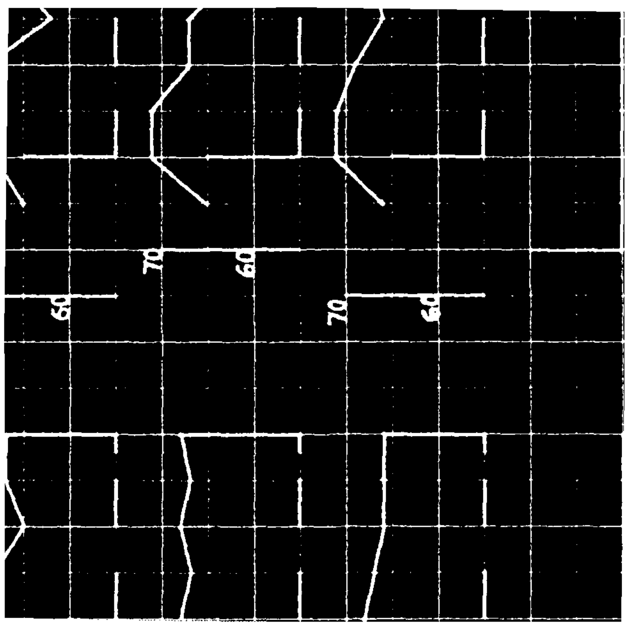

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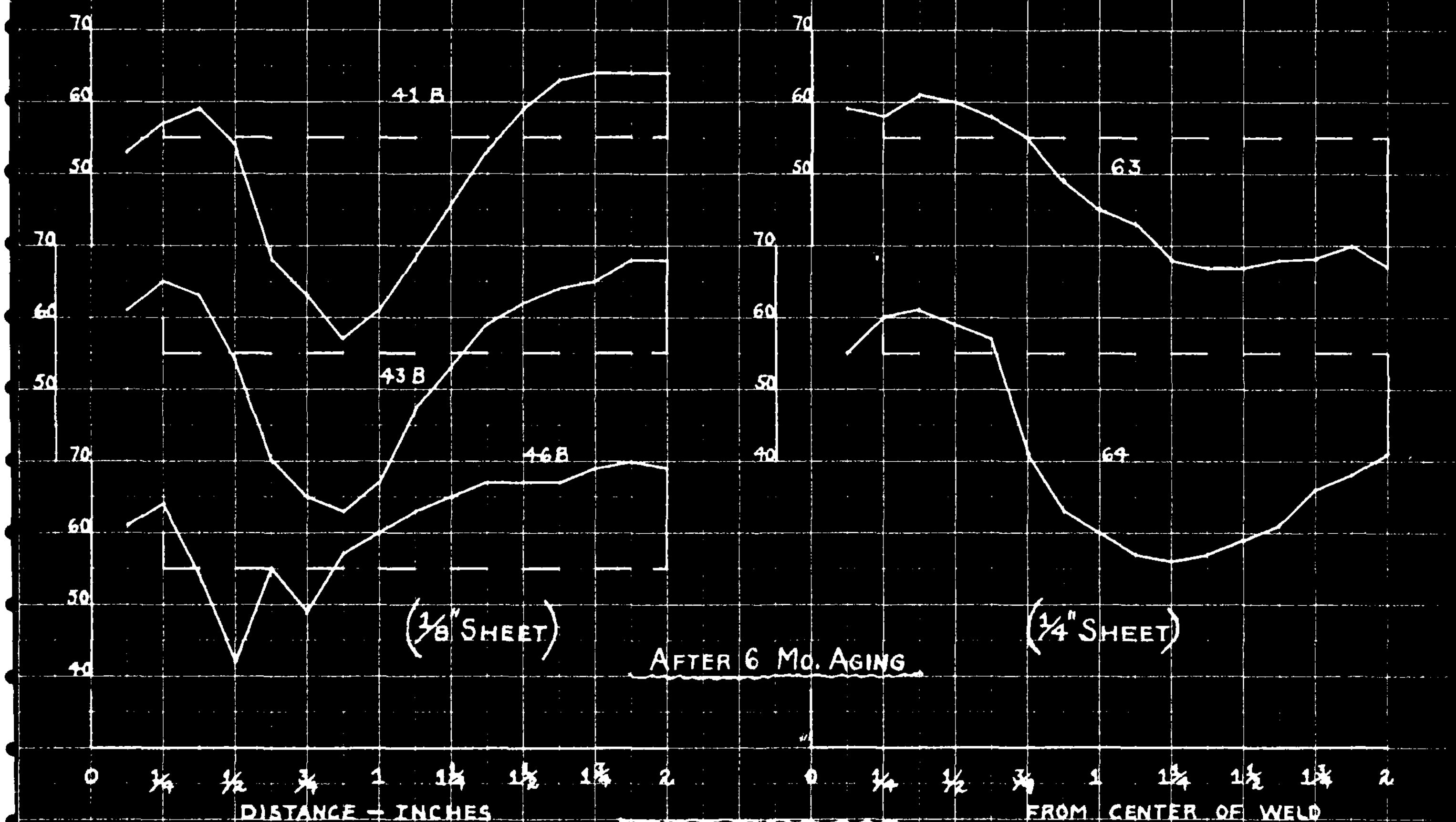

FIG. NO. 5.
REPORT NO. 648/4

WATERTOWN ARSENAL
ROCKWELL "B" HARDNESS
O-A BUTT WELDS
DURAL SHEET

W.L.W.
2/3/33